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(71) Applicant: ATRIX LABORATORIES, INC. [US/US]; 2579 Midpoint Drive, Fort Collins, CO 80525 (US).

(72) Inventors: DUNN, Richard, L.; 5021 Kitchell Drive, Fort Collins, CO 80524 (US). SWANBOM, Deryl, D.; 2579 Midpoint Drive, Fort Collins, CO 80525 (US). BOTZ, Michelle; 2579 Midpoint Drive, Fort Collins, CO 80525 (US). GODOWSKI, Kenneth, C.; 2579 Midpoint Drive, Fort Collins, CO 80525 (US). JEFFERS, Scott; 2579 Midpoint Drive, Fort Collins, CO 80525 (US).

(74) Agent: DAIGNAULT, Ronald, A.; Merchant & Gould P.C., 3100 Norwest Center, 90 South Seventh Street, Minneapolis, MN 55402-4131 (US).

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(57) Abstract

The invention is directed to a filamentous porous film that can act as a support for cellular attachment, growth and organization. The film is formed from filaments which define a matrix structure with pores.

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Filamentous Porous Films and Methods for Producing the Same

Background of the Invention

Significant benefits can be derived from the ability to grow cells *in vitro* on biodegradable supports or scaffolds followed by transplantation to a human needing cells for tissue repair or replacement. Cells that could be grown for such tissue engineering include osteoblasts for new bone, chondrocytes for cartilage, fibroblasts for dermal tissue and retinal pigment epithelial cells (RPE) for the eye.

Some research regarding this aspect of tissue engineering has already been reported. For example, Mikos et al. have prepared poly(glycolic acid) bonded fiber structures for cell attachment and transplantation. *J. of Biomedical Materials Research, Vol. 27, 183 - 189 (1993).* Their preparations involved formation of a composite material between poly(glycolic acid) nonwoven fiber meshes and poly(L-lactic acid) (PLLA) followed by thermal treatment and selective dissolution of the PLLA matrix. Others have investigated porous sheets of polymer for such cell growth. Although the growth of cells on such porous film has been demonstrated, there are difficulties with such an approach.

The task of tissue engineering is complicated by the need of most cells to have special surfaces for attachment, proliferation and cell interactions. Additionally, some cells have distinctly different basal and apical characteristics and are polar in nature so that they function properly only when they are properly oriented.

There is a need, therefore, for a technique to develop and grow cells *in vitro* in a manner such that they will function properly when implanted. To this end, biodegradable polymers are needed to act as a scaffold or support for the development and growth of such cells. The scaffold should allow the growing cells to organize and develop special cellular function such as cell attachment, proliferation and maintenance of distinct basal and apical characteristics.

Summary of the Invention

These needs are met by the present invention which provides a biodegradable scaffold for *in vitro* cell cultures, and a process for preparation of that scaffold. In particular, the biodegradable scaffold provides a suitable support for organization, proper attachment and growth of cells, especially those with special cellular functions.

In general, the invention is directed to the biodegradable scaffold which is composed of a filamentous porous thin film. The invention as well is directed to a process for preparing the filamentous porous film, and a method of using the filamentous porous film to provide a scaffold for cell growth and tissue engineering.

The filamentous, porous film can act as a support for cells to attach, grow and organize, including those with special functions and those requiring spatial orientation. The film has a matrix structure with two surfaces and is constructed primarily of filaments. The filaments define pores in the matrix structure. The pores extend from one surface to the other surface without a substantial change in the cross sectional dimensions of the pores. The filaments are composed of a pharmaceutically acceptable, biodegradable, thermoplastic polymer that is substantially soluble in a pharmaceutically acceptable organic solvent and substantially insoluble in aqueous medium and body fluid.

The process of the invention is carried out by applying liquid filaments of a flowable thermoplastic polymer solution onto an aqueous medium in such a manner that a solid filamentous porous film forms. By controlling the viscosity of the polymer solution and applying the polymer solution by any technique that forms droplets or small multiple volumes of the solution, the elongated small multiple volumes of solution, i.e., liquid filaments, can be formed which will result in the formation of a solid filamentous, porous film rather than a smooth, nonporous sheet.

The method of using the filamentous, porous film according to the invention involves use of the film as a scaffold for cell growth in a cell culture method.

Brief Description of the Drawings

Figures 1 through 9 depict scanning electron micrographs of films.

Figures 1 through 3, 8 and 9 illustrate films of the invention.

Figures 4 through 7 illustrate other kinds of films.

Detailed Description of the Invention

The filamentous, porous, biodegradable film of the invention provides a scaffold which can act as a support for proper attachment, growth, and organization of cells including those with special functions and/or those requiring spatial orientation. The film is formed of filaments of a pharmaceutically acceptable biodegradable thermoplastic polymer. The filaments are arranged into a matrix, the interfilament spaces of which constitute pores. These pores are substantially uniformly distributed throughout the entire film including its upper and lower surfaces. The matrix arrangement of the filaments forming the film and the pores of the film are effective for allowing and promoting growth of cells, including those for which a special cellular function is preserved. The film of the invention provides a suitable biodegradable scaffold for cell implantation.

The process for forming the filamentous, porous film according to the invention enables the construction of filaments and their arrangement into the matrix constituting the film of the invention. The process involves applying liquid filaments of a flowable composition onto an aqueous medium to form the solid filaments. The density and arrangement of filaments provide the matrix structure of the film.

The flowable composition is a solution or dispersion of a pharmaceutically acceptable biodegradable thermoplastic polymer in a pharmaceutically acceptable organic solvent. The biodegradable thermoplastic polymer is substantially insoluble in an aqueous medium and body fluid. The organic solvent is slightly to completely soluble in aqueous medium.

The flowable composition is converted into liquid filaments by any process that is capable of converting the flowable composition into small multiple, separate volumes of solution or dispersion. These methods include, for example, spraying, misting, showering, drizzling, squirting, atomizing or aerosolizing. The preferred method of liquid filament formation is aerosolizing. The liquid filaments are applied onto the surface of an aqueous medium, preferably an aqueous medium having a high surface tension so that the liquid filaments rest upon its surface. The liquid filaments of flowable composition on the surface of the aqueous medium transform into solid filaments and the filaments are arranged to provide the matrix constituting the filamentous film.

While not intended as a limitation of the invention, it is believed that under ordinary circumstances, the contact of droplets of the flowable composition with an aqueous surface would form either a sheet or particles rather than filaments, However, by controlling the viscosity of the flowable composition, liquid filaments are formed and transform into solid filaments instead of a sheet or particles. Although the actual mechanism of this surprising result is not fully understood, the multiple small volumes of flowable composition are formed into liquid filaments during the application process when the viscosity of the flowable composition is within a certain range. These liquid filaments impact the aqueous surface and coagulate to form the overlapping solid filaments of the porous film.

Definitions

The term "biodegradable" means that the substance having this characteristic, such as the thermoplastic polymer, will degrade over time by the action of enzymes, by hydrolytic action and/or by other similar mechanisms and includes such characteristics as bioerodable and bioabsorbable.

The term "bioerodible," means that the substance having this characteristic, such as the matrix, will erode or degrade at its surfaces over time due, at least in part, to contact with substances found in the surrounding tissue fluids or cellular action.

The term "bioabsorbable," means that the substance having this characteristic, such as thermoplastic polymer matrix, will be broken down and absorbed within the living body, for example, by a cell or tissue.

The terms "biocompatible" and "pharmaceutically acceptable" mean that the substance having these characteristics, such as the thermoplastic polymer, the solvent and the resulting filamentous porous film, will not cause substantial tissue irritation or necrosis at the implant site.

The term "flowable" means that the substance having this characteristic, such as the thermoplastic polymer solution, is manipulatable, may be transported through an orifice and is incapable of maintaining a definite shape. Flowable includes formulations with a low viscosity or water-like consistency to those with a high viscosity, such as a paste-like material. Advantageously, the flowability of the thermoplastic polymer formulation allows it to conform to irregularities, crevices, cracks, and/or holes on the aqueous medium.

"Special cellular function" means cell functions such as cell attachment, cell proliferation, and maintenance of cell differentiation.

The term "liquid filament" means a non-spherical, string-like or elongated volume of liquid material. The length may become much greater than the width when the viscosity of the flowable composition is sufficiently high or otherwise within a certain range.

"Applying liquid filaments" means using any method of producing liquid filaments such as spraying, misting, showering, drizzling, squirting, atomizing or aerosolizing.

Thermoplastic polymer

Thermoplastic polymers useful in this invention include thermoplastic polymers that are biodegradable. The thermoplastic polymers are substantially insoluble in an aqueous or body fluid medium but are capable of substantially dissolving in a water-soluble carrier, or solvent, to form the flowable composition. Upon contact between the flowable composition and an aqueous medium, the thermoplastic polymer component in the flowable composition will coagulate or

precipitate to form a solid material, and the solvent component will dissipate into the aqueous medium. Flowable compositions with these characteristics have generally been described in US Patent No's. 4,938,763; 5,077,049; 5,324,519; 5,632,727; 5,599,552; 5,702,716; 5,487,897; 5,660,849;5,278,201; 5,198220; 5,447,725 and 5,242,910, the disclosures of which are incorporated herein by reference.

Thermoplastic polymers that are suitable for use in the thermoplastic polymer solution generally include any having the foregoing characteristics. Suitable thermoplastic polymers include those with repeating functional group units in the polymer backbone, including but not limited to such functional group units as ester (including those formed from hydroxycarboxylic acids and those formed from polycarboxylic acids and polyols), amide (including those formed from aminocarboxylic acids and those formed from polycarboxylic acids and polyamines), urethane, carbonate, anhydride, esteramide, dioxanone, acetal, ketal, and phosphazene. Structural classes of such polymers are disclosed in US Patent No's 4,938,763; 5,077,049; 5,324,519; 5,632,727; 5,599,552; 5,702,716; 5,487,897; 5,660,849;5,278,201; 5,198220; 5,447,725 and 5,242,910, the disclosures of which are incorporated herein by reference. Preferred thermoplastic polymers have repeating ester units within their backbones. Especially preferred thermoplastic polymers are those formed from such monomeric units as lactide, glycolide, caprolactone, hydroxbutyrate, C2 to C6 diol ester with a dicarboxylate selected from oxalate, malonate or succinate, and any combination thereof as a copolymer or terpolymer with random, ordered or block distribution of the various monomeric units.

The Brookfield relative viscosity measurement of the flowable composition indicates the concentration of thermoplastic polymer, the interaction between the thermoplastic polymer and solvent and the molecular weight of the thermoplastic polymer itself. The relative viscosity of the flowable composition determines how readily or how slowly it will flow. The relative viscosity also determines whether the flowable composition will form spherical droplets which coalesce into particles or sheets, or elongated droplets (liquid filaments) which coalesce into solid filaments. In general, the Brookfield relative viscosity of the flowable composition

will range from about 1,000 to about 90,000 centipoise (cps) and preferably from 1,000 to about 10,000 cps in order to form the filamentous film of the invention.

Organic Solvent

Suitable organic solvents for use in the flowable composition are those which are pharmaceutically acceptable and will at least partially dissolve the thermoplastic polymer. According to the invention, the solvent has a solubility in aqueous medium, ranging from moderately soluble to completely miscible and is capable of diffusing into an aqueous medium such as water, hydrogel, agar and the like.

Classes of pharmaceutically acceptable organic solvents suitable for the present invention include aliphatic and alicyclic alcohols and polyols, aliphatic, alicyclic and aromatic esters, aliphatic and alicyclic lactams, aliphatic and alicyclic lactones, aliphatic and alicyclic amides, aliphatic and alicyclic carbonates, aliphatic and alicyclic acids, aliphatic and alicyclic ethers, aliphatic and alicyclic sulfoxides and sulfones, heterocyclic compounds, and aliphatic and alicyclic ketones. Examples of such organic solvents include those disclosed in US Patent No's. 4,938,763; 5,077,049; 5,324,519; 5,632,727; 5,599,552; 5,702,716; 5,487,897; 5,660,849;5,278,201; 5,198220; 5,447,725 and 5,242,910, the disclosures of which are incorporated herein by reference. Specific examples include N-methyl-2-pyrrolidone (NMP), 2-pyrrolidone, propylene carbonate, ethylene carbonate, dimethyl carbonate, acetic acid, lactic acid, heptanoic acid, 2-ethoxyethyl acetate, ethyl acetate, methyl acetate, ethyl lactate, ethyl butyrate, diethyl malonate, diethyl glutonate, tributyl citrate, diethyl succinate, tributyrin, isopropyl myristate, dimethyl adipate, dimethyl succinate, dimethyl oxalate, dimethyl citrate, triethyl citrate, acetyl tributyl citrate, glyceryl triacetate, acetone, methyl ethyl ketone, 2-ethoxyethanol, ethylene glycol dimethyl ether, glycofurol, glycerol formal, 1,3-butyleneglycol, isopropylidene glycol (2,2-dimethyl-1,3-dioxolone-4-methanol; Solketal, dimethylformamide, dimethylacetamide; dimethylsulfoxide (DMSO), dimethylsulfone, tetrahydrofuran, M-caprolactone, butyrolactone, caprolactam, such as N,N-dimethyl-m-toluamide, and 1-dodecylazacycloheptan-2-one and any mixture of two or more of the organic solvents.

The choice of solvent will also depend upon its rate of evaporation and the rate at which it promotes coagulation of thermoplastic polymer from the flowable composition. The rate of evaporation will affect the polymer concentration in the liquid filaments and will change the physical form of coagulation if the polymer concentration changes dramatically. Generally, the organic solvent is chosen so that minimal evaporation occurs during the liquid filament formation and transition to solid filaments. The rate of promotion of coagulation will depend upon the solubility of the organic solvent in water. The highly soluble solvents promote a rapid rate of coagulation while the slightly soluble solvents promote a slow rate of coagulation. Generally, the rate of coagulation will be moderate so that filament formation can occur.

The concentration of thermoplastic polymer in the flowable composition also affects the ability to form filaments. Generally, this concentration may range from about 0.01 gram of thermoplastic polymer per ml of solvent to an about saturated concentration, preferably from about 0.1 gram per ml to an about 2.0 gram per ml., more preferably from about 0.1 gram per ml to an about 0.7 gram per ml.

Formation of Filamentous Porous Film

In general, the filamentous porous film of the invention is formed by contacting the flowable composition with an aqueous medium. The flowable composition can be applied to the aqueous medium by any technique that converts the flowable composition into liquid filaments. For example, the flowable composition can be applied by spraying, misting, showering, drizzling, squirting, atomizing or aerosolizing. Aerosolization is a preferred method of administration because it minimizes the amount of flowable composition applied to the aqueous medium while maximizing uniformity and pore size. Typically, the flowable composition is placed in the reservoir of an atomizer or spray gun and aerosolized by inert gas pressure. The aerosol flow is directed toward the aqueous medium which it contacts and forms liquid filaments on the surface of the aqueous medium. The aqueous medium preferably has a high surface tension, high density and/or high viscosity so that the liquid filaments of flowable composition do not sink into the

medium but rest upon its surface. Upon application of the liquid filaments to the aqueous medium, the liquid filaments convert into solid filaments as the thermoplastic polymer coagulates to a solid. The result is that the coagulating polymer adopts a filament form as a solid. The filamentous porous film generally has a thickness of about 10 μm to about 100 μm, more preferably from about 20μm to about 50μm.

Structure of the Filamentous Porous Film

The matrix structure of the filamentous porous film defines pores which are a minimum of about 1 μm in size. The pores also range in size from about 1 μm to about 30 μm, preferably from 5 to 10 μm. The filaments diameters are about 0.01-4 μm, preferably 0.1 to 2 μm and lengths of about 1 to 240 μm, preferably 1 to 100 μm. The pores are large enough to permit cells to attach and grow within the pores and the filamentous character of the film permits the nutrient medium to diffuse to and bathe all surfaces of the cell rather than only a portion such as the basal or apical portion.

The matrix structure of the film of the invention has two surfaces with the pores extending substantially uniformly throughout the matrix structure and from one surface to the other. Thus, the pores of the matrix structure communicate through the surfaces. Generally the filamentous porous film will have a porosity in the range of about 20% to about 90% throughout the entire matrix structure, preferably about 60% to 90%.

Use of the Filamentous Porous Film

The filamentous porous film can be used as a scaffold to allow cell growth and tissue engineering such as cell attachment, cell proliferation and maintenance of differentiated cellular function. For example the filamentous, porous film may be used as a scaffold for culturing oriented cells such as RPE cells or osteoblast cells. The filamentous, porous film used as such a scaffold has filament dimensions of 0.1

- 2 microns in diameter and 1 to 100 microns in length and the film has a porosity of 60 to 80 % with pore sizes of 5 to 10 microns.

In use, the film is combined with a nutrient medium such as Dulbecco's minimum essential medium and the specialized cells transferred from living tissue to the film. Incubating the cell culture will allow the cells to attach, grow and multiply into the pores of interfilament spaces of the entire film. This construct of the filamentous porous film and specialized cells can be used for cellular transplant into patients. The construct will facilitate correct implantation and possibly correct orientation of the specialized cells. As degradation of the thermoplastic polymer proceeds, regenerated specialized cells with a proper function, and possibly a correct orientation will be established such that cellular interactions dependent upon the cellular functions and possibly the orientation will be re-established.

The invention has been described with reference to various specific and preferred embodiments and techniques. However, it should be understood that many variations and modifications may be made while remaining within the spirit and scope of the invention.

Examples

Example 1

Formation of Flowable Thermoplastic polymer Solution

A thermoplastic copolymer poly(DL-lactide-co-glycolide) (PLG) with 50 mol % of the polymer being glycolide was dissolved in N-methyl-2-pyrrolidone (NMP). The copolymer, with an intrinsic viscosity (IV) of 1.03 dl/g, can be purchased from Birmingham Polymers, Inc. (BPI). The copolymer solution, prepared by placing 20 g of the copolymer and 80 g of NMP in a glass jar, was initially mixed with a spatula or wooden stick. The nitrogen-purged jar was kept at room temperature for one hour and then placed in a room temperature shaker. The contents were shaken until all the polymer was in solution (generally 24 to 48 hours).

Examples 2-12:

Additional copolymers of PLG, poly(DL-lactide-co-glycolide) with acid end groups (PLG-H) and poly(DL-lactide-caprolactone) (PLC) were dissolved in NMP using the same procedure described in example 1. The copolymer manufacturers were either Birmingham Polymers, Inc. (BPI) or Boehinger Ingelheim (BI). The compositions, intrinsic viscosities, manufacturers and solution concentrations are summarized in Table 1.

Table 1: Summary of Flowable Compositions (Examples 1 - 12)

Example	Copolymer	Copolymer Ratio	Intrinsic Viscosity	Manufacturer	wt %
1	PLG	50/50	1.03 dL/g	BPI	20
2	PLG	50/50	0.7 dL/g	BPI	20
3	PLG	50/50	0.26 dL/g	BPI	20
4	PLG	75/25	1.08 dL/g	BPI	20
5	PLG	75/25	0.72 dL/g	BPI	20
6	PLG	75/25	0.31 dL/g	BPI	20
7	PLC	75/25	0.74 dL/g	BPI	20
8	PLG	65/35	1.02 dL/g	BPI	20
9	PLG	65/35	0.65 dL/g	BPI	20
10	PLG	65/35	0.36 dL/g	BPI	20
11	PLG-H	50/50	0.4 dL/g	BI	30
12	PLG-H	50/50	0.4 dL/g	BI	20

Example 13:

A film was prepared from the flowable composition in Example 1. The aerosol applicator (Air Brush, Badger Model 150) was connected to the propellant source (nitrogen gas) and cleaned for approximately 15 to 30 seconds by spraying acetone through the unit. Following complete removal of any acetone residue, a 1 cc vial containing the polymer formulation was attached to the applicator. The aerosol unit was activated over a sterile purified agar plate. The unit was held approximately 3 to 6 inches from the plate to avoid blowing the film from the agar plate and moved in a circular motion to ensure even coverage.

The aerosol unit was deactivated after 15 seconds. The activation time, which determines the film thickness, is based on the appearance of the film. That is, the surface will appear matted or flat when the thickness is about 50 μm but glossy when the thickness is greater than approximately 70 μm.

The agar plate was filled with approximately 25 ml of sterile water with a pipette to float the film above the agar surface and then rotated to allow water to flow underneath the film. To remove the film from the agar plate, a piece of Teflon was placed underneath the film with the assistance of sterile forceps. The Teflon piece and the film were transferred to a petri dish. Approximately 25 ml of sterile water was added to the petri dish allowing the removal of the Teflon piece. After 15 minutes, the rinse water was removed and the film was washed with an additional 25 ml of sterile water. A Teflon piece was placed underneath the film for removal from the petri dish. The film was dried overnight on the Teflon piece in a laminar flow hood.

The film was cut into smaller pieces (approximately 10 X 10 mm) and placed into a ATRISORB® case housing and placed into a nitrogen purged pouch. The film pieces were sterilized using gamma irradiation at 14 kGy +/- 10%. This corresponds to a 10^{-6} sterility assurance level (SAL) with a bioburden level of approximately 1 CFU per film.

The film thickness, measured with digital calipers, varied from 35 to 60 μm (43 μm average) before irradiation and from 25 to 50 μm (35 μm average) after irradiation. The overall handling characteristics of the film was very good.

Example 13 - 24:

Additional films were prepared from flowable compositions prepared in examples 2 - 12 using the procedure described for example 13. Table 2 contains a summary of the film characteristics.

Table 2: Summary of Film Characteristics

Example	Flowable Composition	Volume used, µl	Spray Time, sec	Thickness pre-irradiation, µm [1]	Thickness after irradiation, µm [1]	Overall Handling Characteristics
13	Ex. 1	50	15	43	35	very good
14	Ex. 2	100	10-15	37	33	good; cracking
15	Ex. 3	75	5-10	10	not measured	not good ; very flaky
16	Ex. 4	25	15-20	28	34	good / fair; sticky
17	Ex. 5	25	not timed	35	53	fair; some stickiness
18	Ex. 6	50	not timed	31	35	not good; cracking
19	Ex. 7	50	not timed	not measured	not measured	not good; sticky
20	Ex. 8	25	not timed	28	19	fair; very thin and sticky
21	Ex. 9	50	not timed	45	28	not good; very brittle
22	Ex. 10	100	not timed	25	not measured	not good; stuck to plate and fell apart
23	Ex. 11	25	not timed	29	not measured	good; some stickiness
24	Ex. 12	50	not timed	31	25	fair; brittle

[1] Average

Examples 25 - 46:

Flowable compositions of PLG, (PLG-H) and poly(DL-lactide) (PLA) were prepared as described in example 1. The polymer compositions, inherent viscosities, manufacturers and solution concentrations are summarized in Table 3.

Table 3: Summary of Flowable Compositions (Examples 25 -46)

Example	Polymer	Copolymer Ratio	Intrinsic Viscosity	Manufacturer	wt %
25	PLG	50/50	1.03 dL/g	BPI	10
26	PLG	50/50	1.03 dL/g	BPI	20
27	PLG	50/50	1.03 dL/g	BPI	30
28	PLG	50/50	0.26 dL/g	BPI	10
29	PLG	50/50	0.26 dL/g	BPI	20
30	PLG	50/50	0.26 dL/g	BPI	30
31	PLG	75/25	0.31 dL/g	BPI	10
32	PLG	75/25	0.31 dL/g	BPI	20
33	PLG	75/25	0.31 dL/g	BPI	30
34	PLG	75/25	1.08 dL/g	BPI	10
35	PLG	75/25	1.08 dL/g	BPI	20
36	PLG	75/25	1.08 dL/g	BPI	30
37	PLGH	50/50	0.48 dL/g	BI	10
38	PLGH	50/50	0.48 dL/g	BI	20
39	PLGH	50/50	0.48 dL/g	BI	30
40	PLGH	50/50	0.48 dL/g	BI	40
41	PLA	-	0.33 dL/g	BPI	10
42	PLA	-	0.33 dL/g	BPI	20
43	PLA	-	0.33 dL/g	BPI	30
44	PLA	-	0.83 dL/g	BPI	10
45	PLA	-	0.83 dL/g	BPI	20
46	PLA	-	0.83 dL/g	BPI	30

Examples 47- 68:

Films were prepared from the flowable compositions prepared in examples 25 - 46. The aerosol applicator (Air Brush, Badger Model 150) was connected to the propellant source (nitrogen gas) and cleaned for approximately 15 to 30 seconds by spraying acetone through the unit. Following complete removal of any acetone residue, a 3 cc vial containing the polymer formulation was attached to the applicator. The aerosol unit was activated over a sterile purified agar plate. The unit

was held approximately 3 to 6 inches from the plate to avoid blowing the film from the agar plate and a circular motion was used to ensure an even coverage.

The agar plate was filled with approximately 25 ml of sterile water with a pipette to float the film above the agar surface and then rotated to allow water to flow underneath the film. To remove the film from the agar plate, a piece of Teflon was placed underneath the film with the assistance of sterile forceps. The Teflon piece and the film were transferred to a petri dish. Approximately 25 ml of sterile water was added to the petri dish allowing the removal of the Teflon piece. After 15 minutes, the rinse water was removed and the film was washed with an additional 25 ml of sterile water. A Teflon piece was placed underneath the film for removal from the petri dish. The film was dried overnight on the Teflon piece in a laminar flow hood.

Pieces of the film were placed in vials, frozen at -86°C for approximately one hour, and lyophilized overnight to completely dry the films. The thickness was measure using digital calipers. The film was then mounted and coated with gold for viewing by scanning electron microscopy (SEM). The structure of the film was characterized and reported in Table 4.

The Brookfield relative viscosity was measured for each flowable composition.

Table 4: Characterization of Films (Examples 47 - 68)

Example	Flowable Composition	Thickness, µm	Brookfield Relative Viscosity, cps	Structure Characteristics
47	Ex. 25	90	112	plate like material with foam like porous structure
48	Ex. 26	150	1,176	filament structure with bead like masses
49	Ex. 27	310	72,160	broad filaments that melt together
50	Ex. 28	310	24	solid surface; no filaments
51	Ex. 29	170	40	plate like material with foam like porous structure
52	Ex. 30	190	88	plate like material with foam like porous structure

Example	Flowable Composition	Thickness, µm	Brookfield Relative Viscosity, cps	Structure Characteristics
53	Ex. 31	not measured	16	solid smooth surface; see Figure 7 (2020X)
54	Ex. 32	130	64	plate like structures
55	Ex. 33	150	248	plate like structures with early stages of filament formation; see Figure 6 (2020X)
56	Ex. 34	230	360	plates with some underlying filaments
57	Ex. 35	210	8,526	filament structure; starting to merge together; see Figure 8 (2020X)
58	Ex. 36	430	86,880	thick network with smaller rough and rigid filaments; tree like
59	Ex. 37	200	24	foam like structure with plate formation
60	Ex. 38	140	280	flat surface with sporadic pores; beginnings of filament formation
61	Ex. 39	1709	2696	filaments with round sphere like masses
62	Ex. 40	70	19,840	thick broad filaments laying over one another; see Figure 9 (2020X)
63	Ex. 41	130	16	very small spheres in a porous structure; foam core
64	Ex. 42	110	48	flat plate formation
65	Ex. 43	200	192	flat plates melting into a solid structure
66	Ex. 44	80	80	large pores; foam structure with plate like structure
67	Ex. 45	70	1,304	filaments laying on top of each other; melting and branching characteristics
68	Ex. 46	50	15,110	thick broad filaments with some melting together

Examples 69 - 77:

Films from examples 13 -23 were evaluated for *in vitro* growth of human osteoblast cells. Osteoblasts were allowed to grow for three weeks in cell growth medium RPMI 1640 with 10% fetal calf serum and 2 mM glutamine. The film

clinical handling characteristics as well as osteoblast attachment and growth were evaluated. The results are summarized in Table 5.

Table 5: Osteoblast Cell Growth on Films:

Film Handling (Examples 69 - 77)

Example	Film	Sticking Before Hydration	Sticking After Hydration	Curling Before Hydration	Curling After Hydration
69	Ex. 13	slight	moderate	slight	slight
70	Ex. 14	moderate	moderate	none	moderate
71	Ex. 16	moderate	moderate	slight	moderate
72	Ex. 17	none	none	moderate	severe
73	Ex. 18	moderate	moderate	none	-
74	Ex. 20	slight	none	moderate	severe
75	Ex. 21	moderate	severe	slight	slight
76	Ex. 22	slight	moderate	slight	slight
77	Ex. 23	slight	severe	moderate	moderate

Table 6: Osteoblast Cell Growth on Films:

Growth Results (Examples 69 - 77)

Example	Film	Overall Cell Growth	Cell Growth on Both Sides of Film	Nodule Present	Cells Inside Film	Good Cell Growth Around Film	Overall Evaluation
69	Ex. 13	10+	yes	yes	yes	yes	very good
70	Ex. 14	7-8+	yes	yes	yes	yes	good / fair
71	Ex. 16	5+	ND	no	ND	yes	good
72	Ex. 17	3+	ND	no	ND	no	fair
73	Ex. 18	5+	ND	no	ND	no	fair / poor
74	Ex. 20	3+	ND	no	ND	no	fair
75	Ex. 21	6+	yes	no	yes	yes	fair
76	Ex. 22	5+	ND	no	ND	yes	fair
77	Ex. 23	9-10+	yes	yes	yes	yes	very good

Examples 78-86:

Films from examples 13 -23 were evaluated for *in vitro* growth of Human Fetal Retinal Pigment Epithelial Spheroids (HFRPE). Sheets of HFRPE cells were isolated and loosely attached to the films in the presence of Dulbecco's minimum essential medium. Within 48 to 72 hours, the cells attached themselves firmly to the polymer films. The HFRPE cells proliferated and covered each piece of film tested. The cells did not dedifferentiate, an important indication that the films provide a suitable attachment structure. They possessed a cuboidal morphology with numerous apical microvilli. The HFRPE cells produced extracellular matrix (collagen type IV) at their basal side, filling the pores of the film. All the isolated cells were pigmented and expressed cytokeratine. *In vivo*, the transplanted films degraded within 2-3 weeks without any signs of inflammation in rabbit eyes.

Table 7: HFRPE Cell Growth on Films

Film Handling (Examples 78 - 86)

Example	Film	Sticking Before Hydration	Sticking After Hydration	Curling Before Hydration	Curling After Hydration
78	Ex. 13	slight	slight	none	slight
79	Ex. 14	very slight	very slight	none	none
80	Ex. 16	slight	very slight	very slight	very slight
81	Ex. 17	slight	very slight	none	slight
82	Ex. 18	none	very slight	none	none
83	Ex. 20	very slight	none	none	none
84	Ex. 21	none	none	none	slight
85	Ex. 22	slight	very slight	none	very slight
86	Ex. 23	very slight	very slight	very slight	very slight

Table 8: HFRPE Cell Growth on Films

Growth Results (Examples 79 - 86)

Example	Film	Cell Adhesion	Cell Proliferation on Plate	Overall Evaluation
78	Ex. 13	yes	yes	very best
79	Ex. 14	could not manipulate	could not manipulate	brittle
80	Ex. 16	could not manipulate	could not manipulate	brittle
81	Ex. 17	yes	yes	not given
82	Ex. 18	could not manipulate	could not manipulate	brittle
83	Ex. 20	yes	yes	not given
84	Ex. 21	yes	yes	not given
85	Ex. 22	yes	yes	not given
86	Ex. 23	yes	no	not given

Example 87: SEM Photos

Films prepared as examples 13, 15, 18 and 23 were place in vials, frozen at -86° C for approximately one hour, and lyophilized overnight to completely dry the films. The thickness was measured using digital calipers. The films were then mounted and coated with gold for viewing by scanning electron microscopy (SEM). The structure of each film was characterized.

The film from example 13 can be seen in Figure 1 (2020X) and Figure 2(cross-section, 2100X). The film is composed of many filaments of varying widths that weave together to form a mesh-like matrix. The film from example 23 can be seen in Figure 3 (2020X). Again, the example 23 film is composed of filaments forming a mesh-like matrix. Example 23 appears to have larger filaments than example 13. Both films have void spaces between the filaments larger than 10 μm, an optimal size for cells to attach and proliferate.

The film from example 15 can be seen in Figure 4 (1010X). This film was too brittle for cell growth experiment and appears porous on one side but non-porous on the opposite side. The film from example 18 can be seen in Figure 5 (2020X). This film had a predominately smooth, plate-like surface and some very small pores. Neither example 15 nor 18 had pores that extending from one side of the polymer to the other side. Likewise, neither film was filamentous.

What is claimed is:

1. A process for preparing a filamentous porous film, comprising: applying liquid filaments of a flowable composition onto an aqueous medium to form a matrix structure of filaments, wherein the flowable composition comprises a pharmaceutically acceptable, biodegradable thermoplastic polymer that is substantially insoluble in an aqueous or body fluid medium, dissolved or dispersed in a pharmaceutically acceptable organic solvent that is moderately soluble to completely miscible in the aqueous or body fluid medium.

2. A process of claim 1, wherein the concentration of thermoplastic polymer is about 10 to 50 wt. % in the organic solvent.

3. The process of claim 1, wherein the thermoplastic polymer is bioerodible.

4. A process of claim 1, wherein the thermoplastic polymer contains repeating functional group units in its polymer backbone, which are selected from hydroxycarboxylic acid ester, polycarboxylic acid and polyol ester, aminocarboxylic acid amide, polycarboxylic acid and polyamine amide, urethane, carbonate, anhydride, esteramide, dioxanone, acetal, ketal, phosphazene and any combination thereof.

5. A process of claim 4, wherein the thermoplastic polymer is formed from at least one monomeric unit selected from the group consisting of lactide, glycolide, caprolactone, hydroxbutyrate , and C_2 to C_6 diol ester with a dicarboxylate selected from oxylate, malonate and succinate, and any combination thereof as a copolymer or terpolymer with random, ordered or block distribution of the various monomeric units.

6. A process of claim 5, wherein the thermoplastic polymer is poly(DL-lactide-co-glycolide).

7. A process of claim 1, wherein the organic solvent is selected from the group consisting of aliphatic and alicyclic alcohols and polyols, aliphatic, alicyclic and aromatic esters, aliphatic and alicyclic lactams, aliphatic and alicyclic lactones, aliphatic and alicyclic amides, aliphatic and alicyclic carbonates, aliphatic and alicyclic acids, aliphatic and alicyclic ethers, aliphatic and alicyclic sulfoxides and sulfones, heterocyclic compounds, and aliphatic and alicyclic ketones.

8. A process of claim 7, wherein the organic solvent is N-methyl-2-pyrrolidone.

9. A process of claim 1, wherein the flowable composition has a viscosity which effectively allows for formation of liquid filaments.

10. A process of claim 9, wherein the flowable composition has a Brookfield relative viscosity of about 1,000 to 90,000 centipoise.

11. The process of claim 1, wherein the step of applying the liquid filaments of flowable composition comprises spraying, misting, showering, drizzling, squirting, atomizing or aerosolizing the flowable composition.

12. The process of claim 11, wherein the step of applying the liquid filaments of flowable composition comprises aerosolizing the flowable composition.

13. The process of claim 1, wherein the aqueous medium is a hydrogel.

14. The process of claim 13, wherein the hydrogel is agar.

15. A filamentous, porous film, comprising: a matrix structure of filaments, interfilament spaces and two surfaces; wherein the interfilament spaces define pores extending from one surface to the other, the pores have cross sectional dimensions which do not substantially change from one surface to the other, and the filaments comprise a pharmaceutically acceptable biodegradable thermoplastic polymer that is substantially insoluble in aqueous fluid or body fluid.

16. The filamentous porous film of claim 15, wherein the thermoplastic polymer contains repeating functional group units in its polymer backbone, which are selected from hydroxycarboxylic acid ester, polycarboxylic acid and polyol ester, aminocarboxylic acid amide, polycarboxylic acid and polyamine amide, urethane, carbonate, anhydride, esteramide, dioxanone, acetal, ketal, phosphazene and any combination thereof.

17. The filamentous porous film of claim 16, wherein the thermoplastic polymer is formed from at least one monomeric unit selected from the group consisting of lactide, glycolide, caprolactone, hydroxbutyrate , C_2 to C_6 diol ester with a dicarboxylate selected from oxalate, malonate and succinate, and any combination thereof as a copolymer or terpolymer with random, ordered or block distribution of the various monomeric units.

18. A filamentous porous film of claim 17, wherein the thermoplastic polymer is poly(DL-lactide-co-glycolide).

19. A filamentous, porous film of claim 15, wherein the filaments have diameters of about 0.01 to about 4 μm.

20. A filamentous, porous film of claim 15, wherein the filaments have lengths of about 1 to about 240 μm.

21. A filamentous, porous film of claim 15, wherein the filamentous porous film has a thickness of about 10 to about 100 μm.

22. A filamentous, porous film of claim 21, wherein the filamentous porous film has a thickness of about 20 to about 50 μm .

23. A filamentous porous film of claim 15, wherein the pores have a cross-sectional dimension of about 5 to about 30 μm.

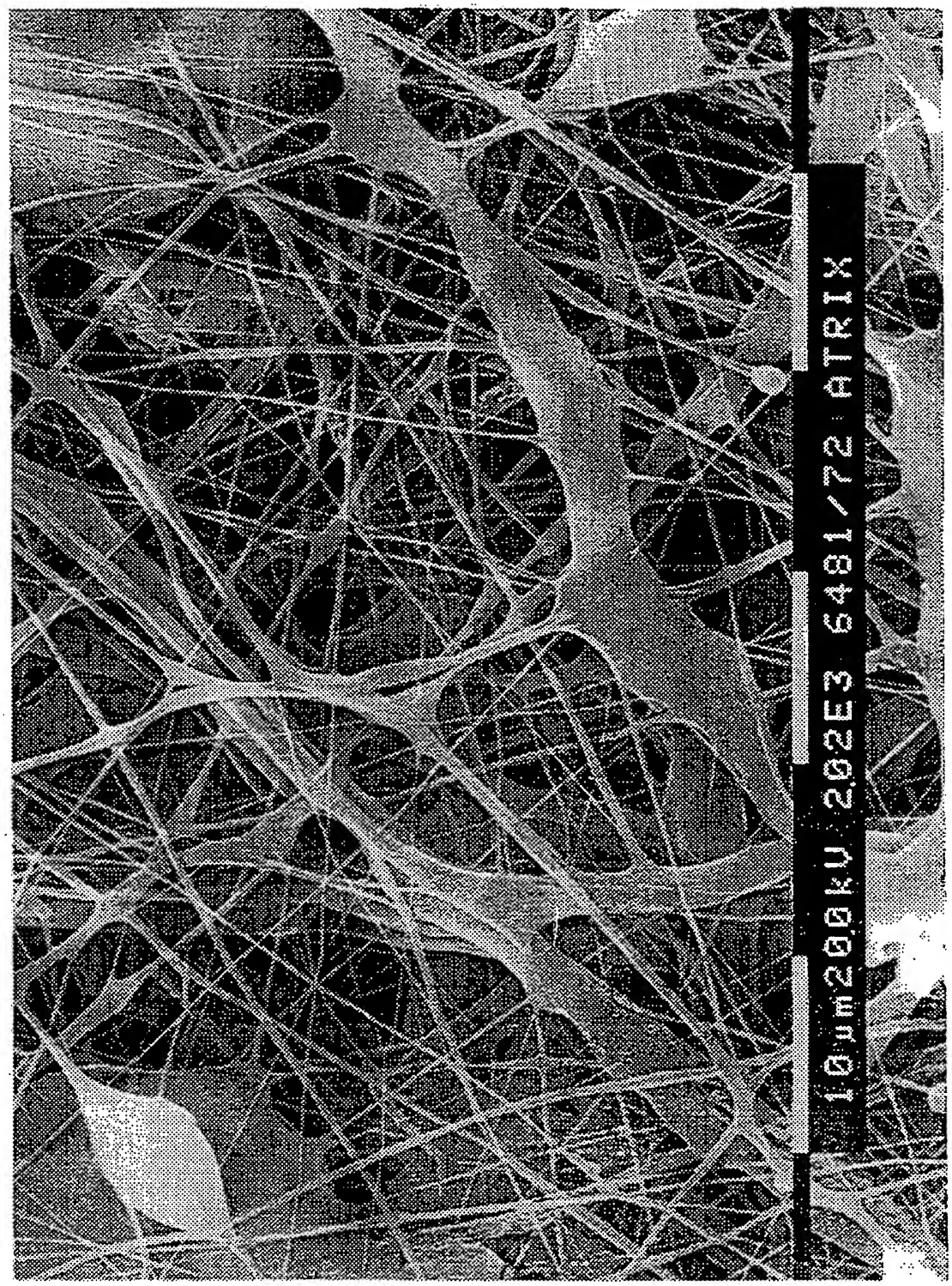

FIG. 1

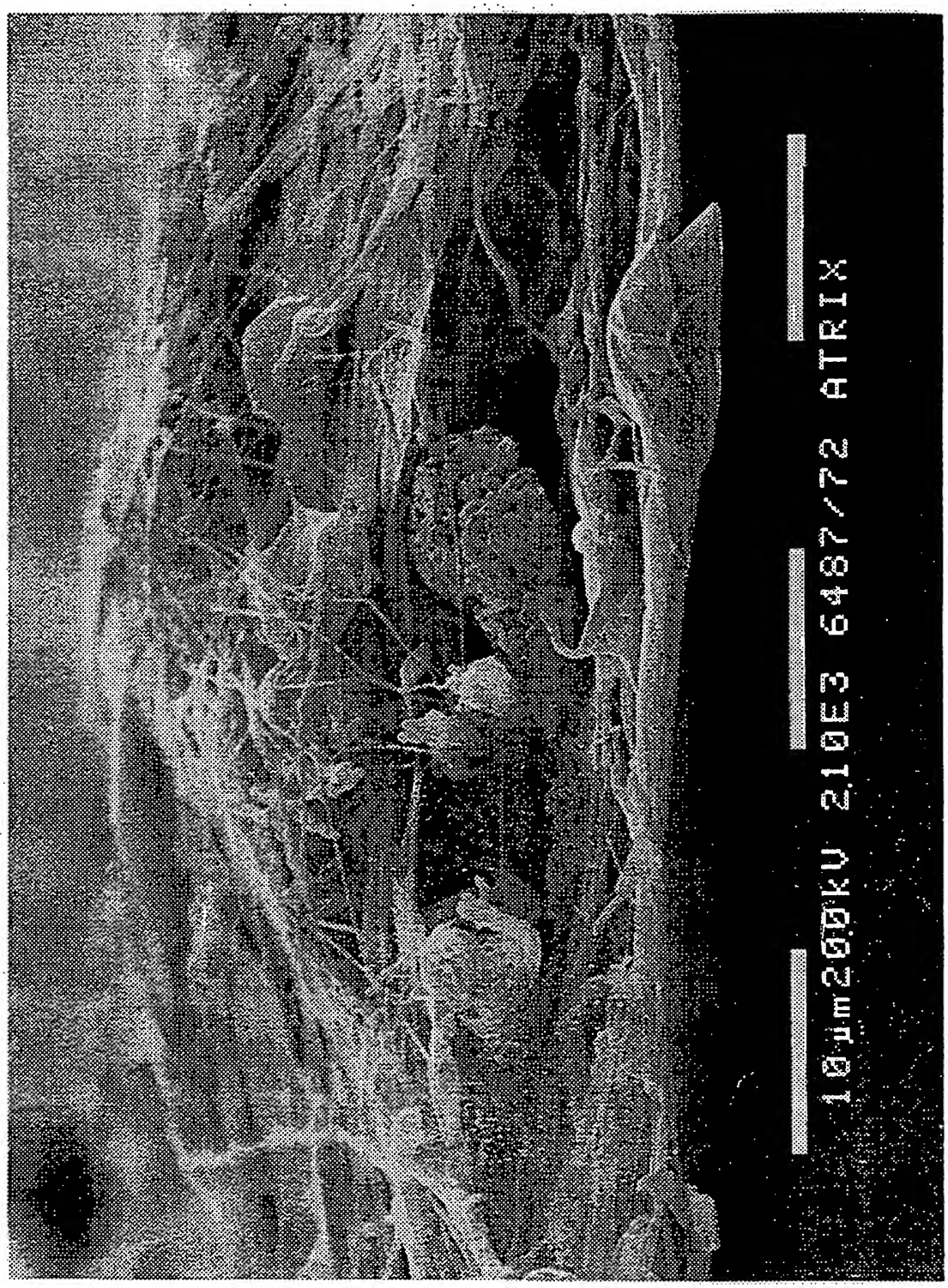

FIG. 2

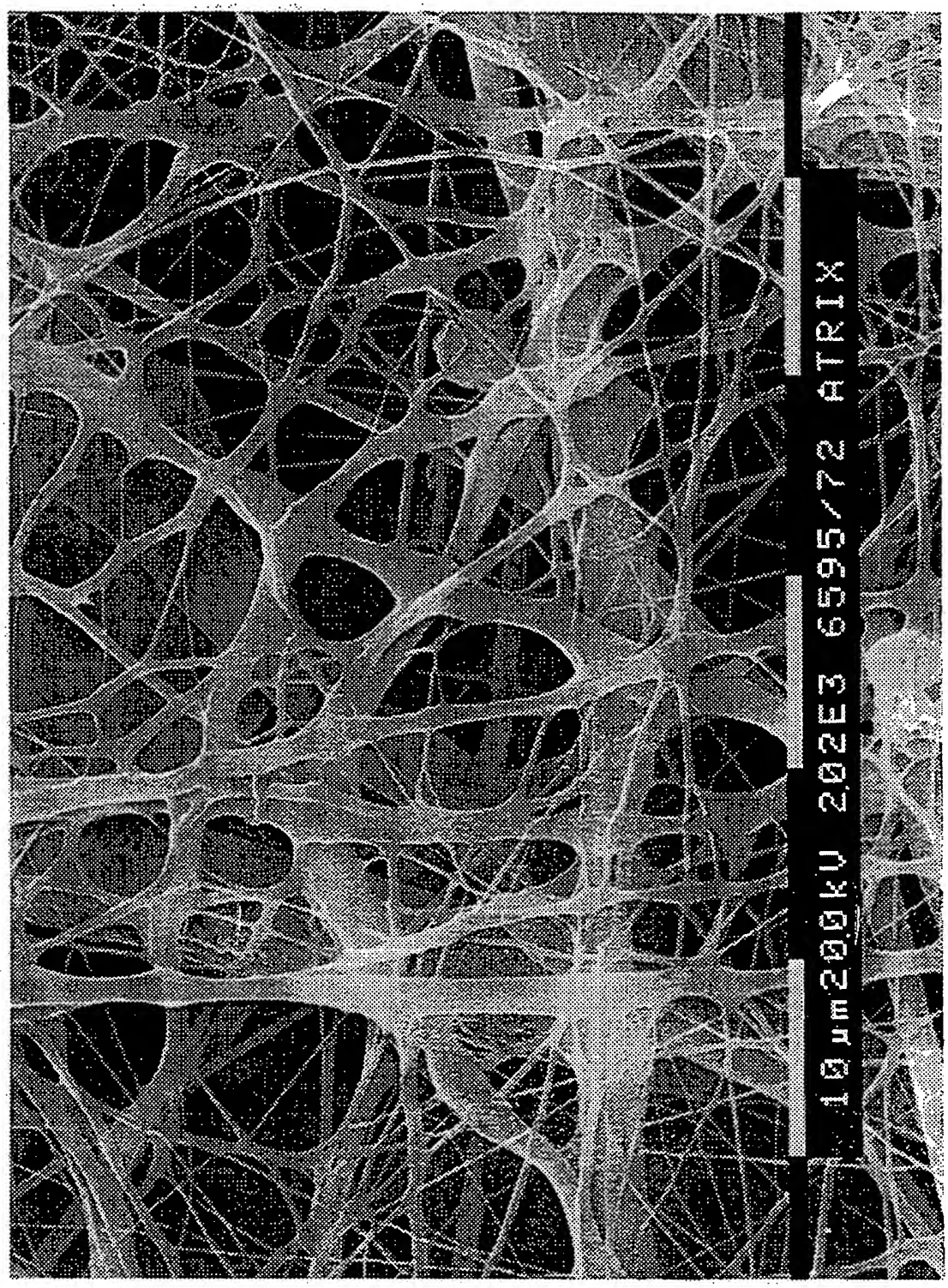

FIG. 3

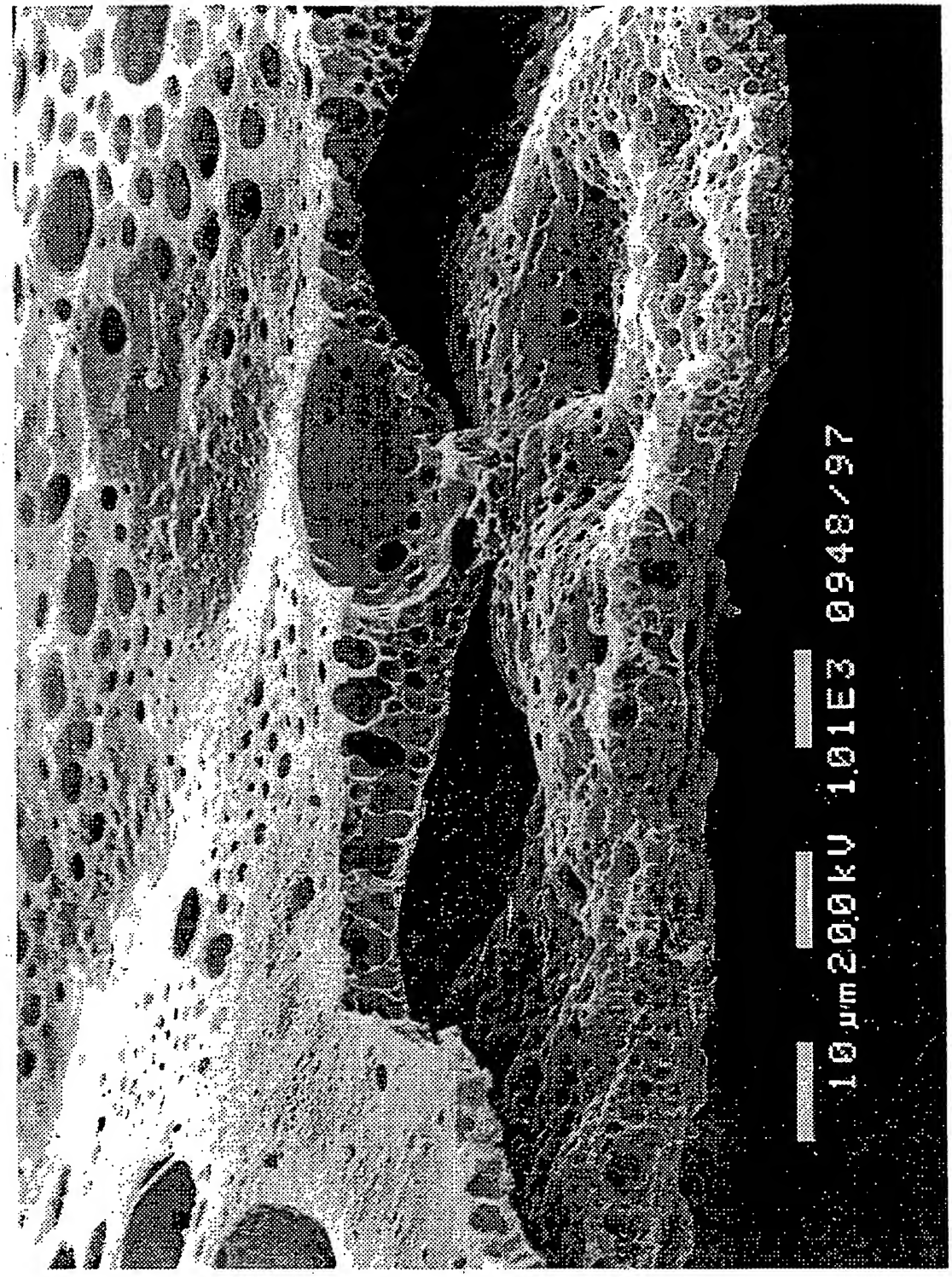

FIG. 4

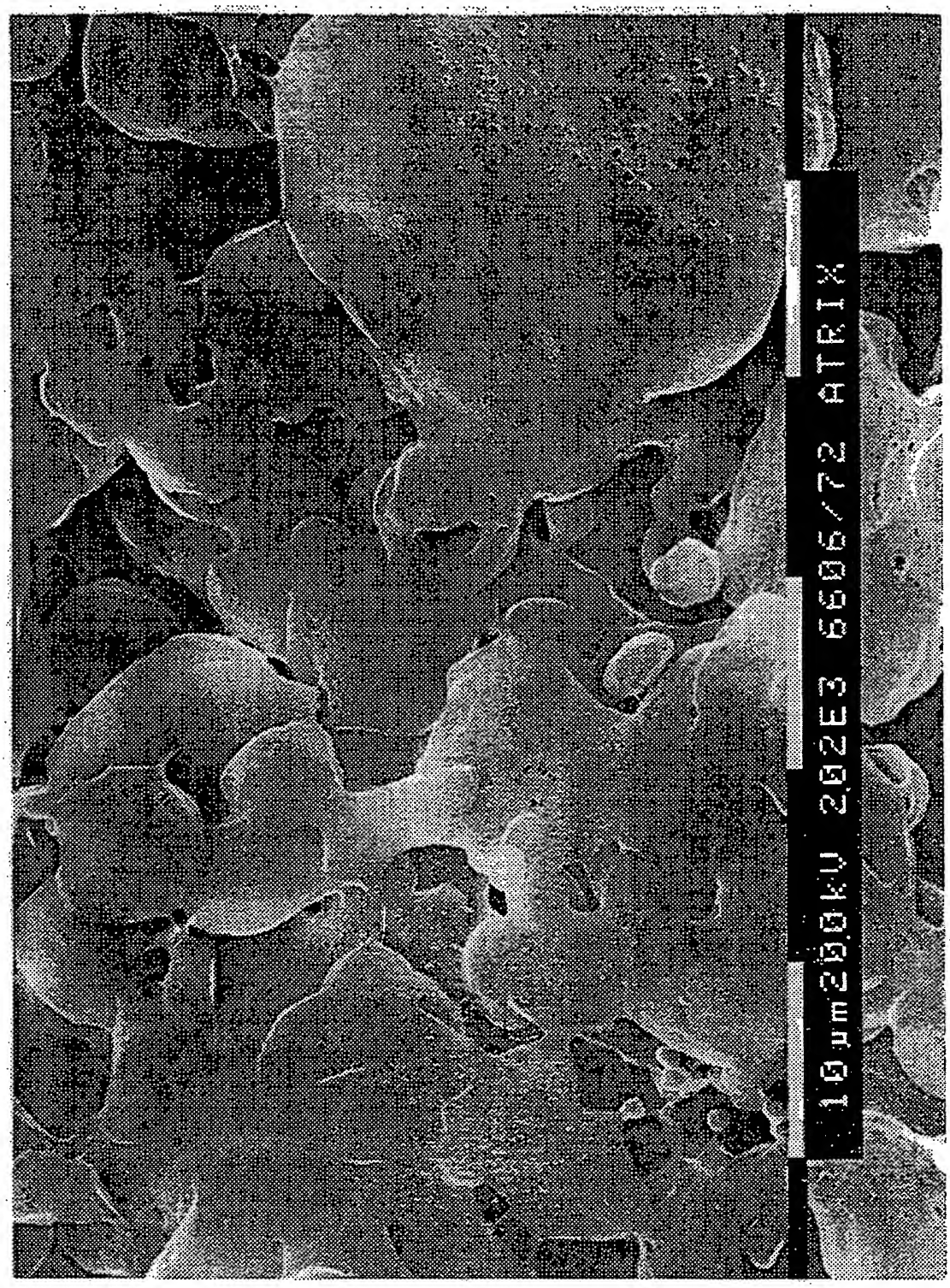

FIG. 5

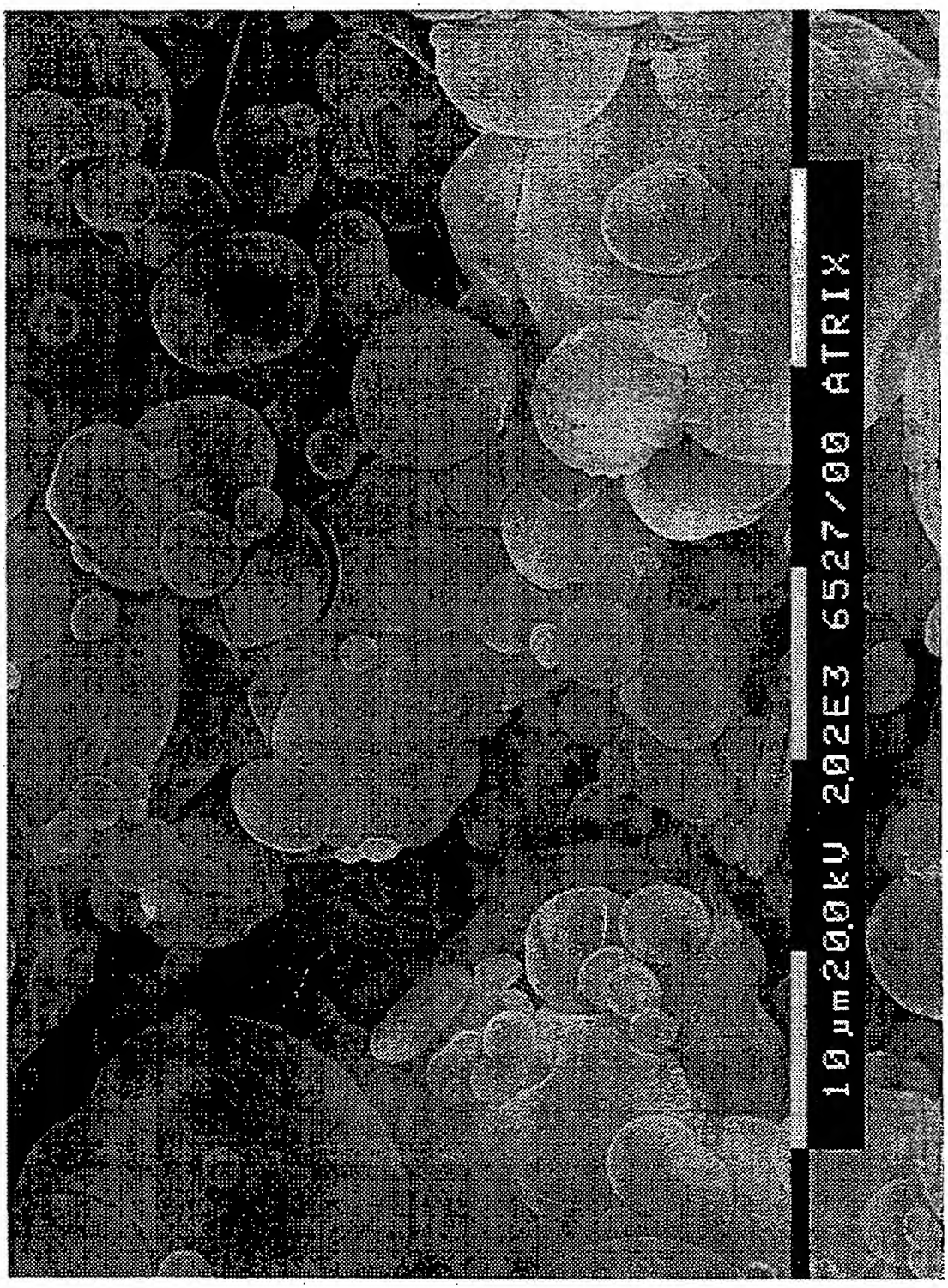

FIG. 6

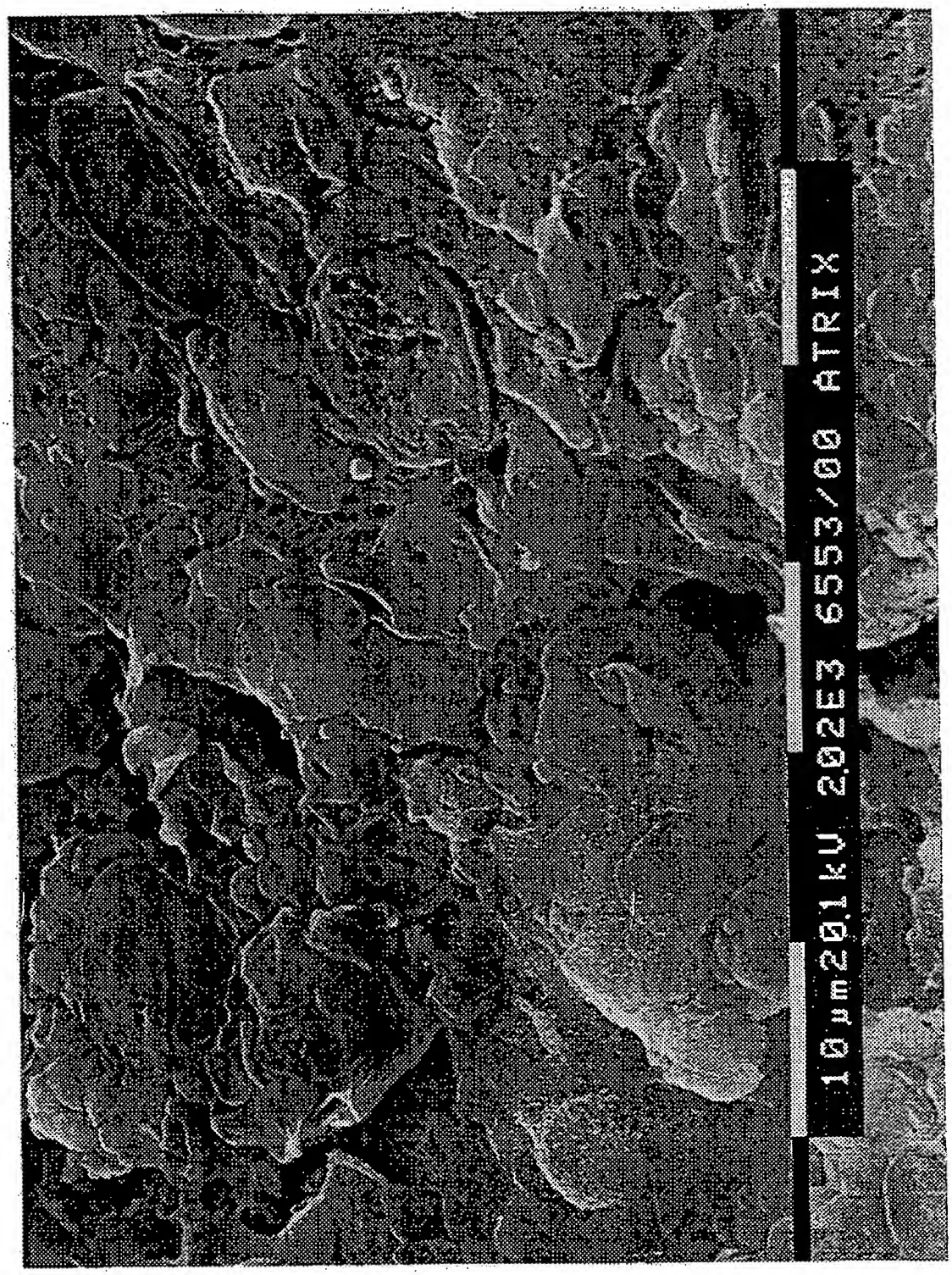

FIG. 7

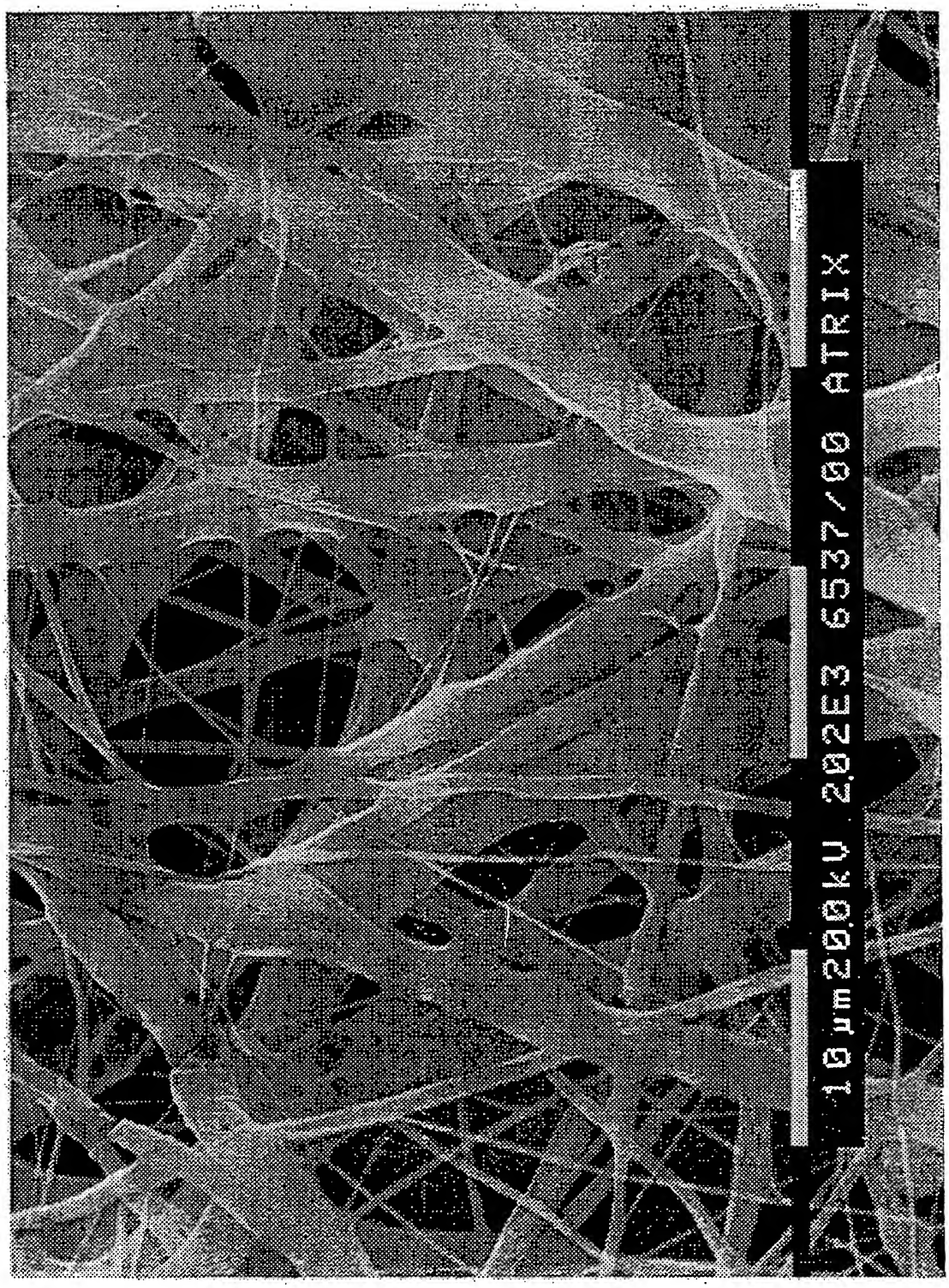

FIG. 8

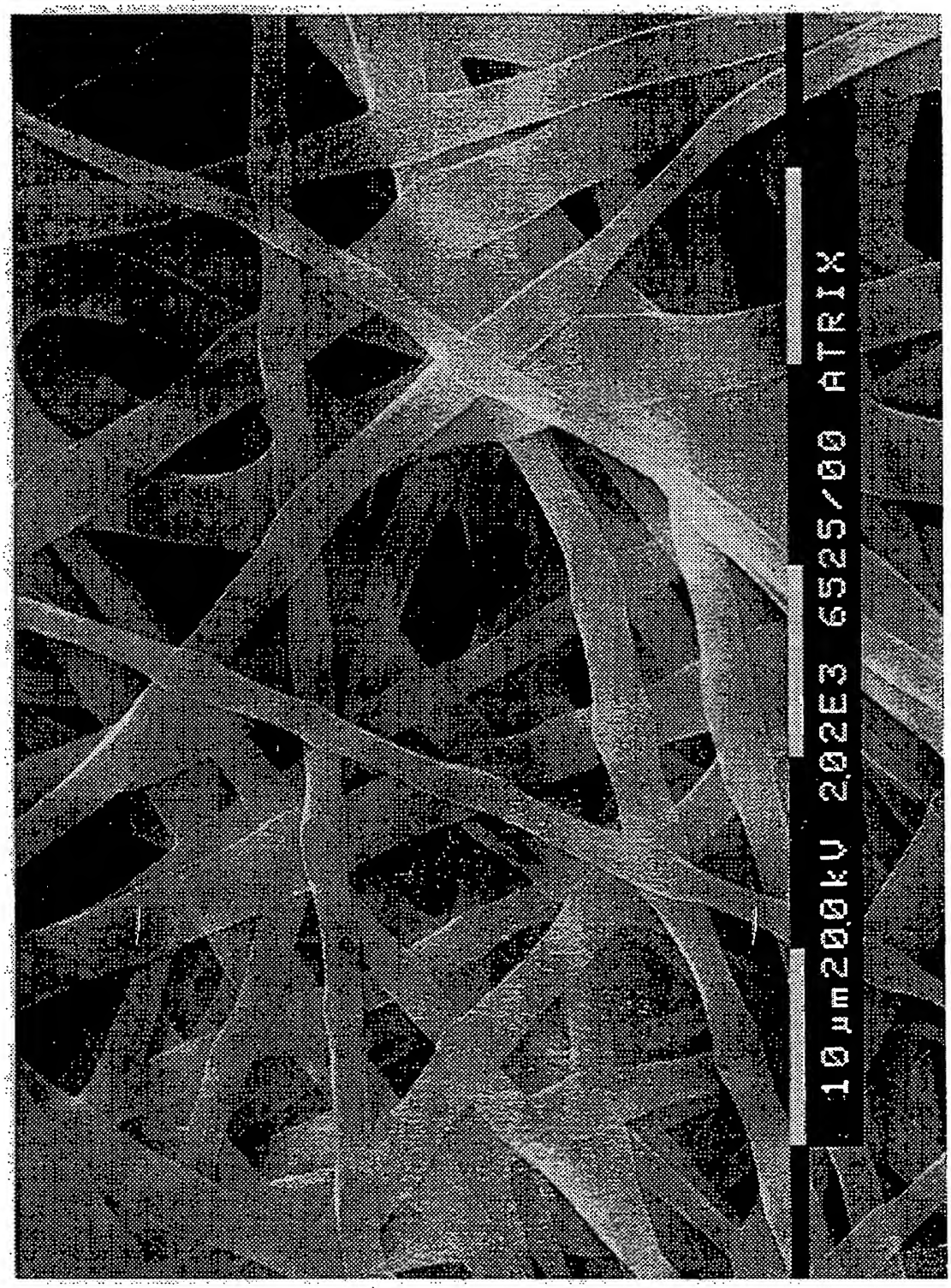

FIG. 9

INTERNATIONAL SEARCH REPORT

International Application No
PC./US 99/15127

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C08J5/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C08J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 722 950 A (FUJITA SHAWN M ET AL) 3 March 1998 (1998-03-03) column 10, line 15 - line 48; claims 1-4	1-14
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 505 (C-0775), 5 November 1990 (1990-11-05) & JP 02 208330 A (ASAHI CHEM IND CO LTD), 17 August 1990 (1990-08-17) abstract	15-23
A	GB 2 223 027 A (G C DENTAL IND CORP) 28 March 1990 (1990-03-28) example 3	1-23
A	EP 0 629 662 A (TOKUYAMA CORP ;UNI CHARM CORP (JP)) 21 December 1994 (1994-12-21) claims 1-3	1-23

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 November 1999	24/11/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

nformation on patent family members

International Application No
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